Protein Content and Amino Acid Composition of Oat Species and Tissues[1]

Y. POMERANZ[2,3], V. L. YOUNGS[2], and G. S. ROBBINS[2], Agricultural Research Service, U.S. Department of Agriculture, Madison, Wisconsin

ABSTRACT

Protein content and amino acid composition were determined in groats and hulls of selections from 11 oat species. The protein-rich groats (17.8 to 37.1%, mean 27.1%) differed substantially and consistently in amino acid composition from the protein-low hulls (2.0 to 8.1%, mean 4.2%); awns resembled hulls in protein content and amino acid composition. Interspecies differences in amino acid composition of hulls were greater than interspecies differences in composition of groats. Groats from the 11 oat species and from 68 selections of *Avena sterilis* contained, on the average, more protein than groats of 289 selections of *A. sativa*, but differences in amino acid composition were small. Hand-dissected, protein-rich germ tissues were relatively high in lysine, histidine, arginine, aspartic acid, and threonine, and low in glutamic acid, proline, and cystine. The relatively high concentrations of lysine, aspartic acid, and threonine, and relatively low concentrations of glutamic acid, proline, and sulfur-containing amino acids in hulls were reflected in differences in composition of commercial oats (*A. sativa* L.) when large-kernel cultivars were contrasted to small-kernel cultivars.

The high protein content of oat groats and excellent chemical score of oat amino acids have prompted in recent years several investigations of this cereal crop. Robbins et al. (1) determined total protein and 17 amino acids in 289 samples of oat groats of the species *Avena sativa*, the oats commercially grown in the U.S. The groats contained 12.4 to 24.4% total protein (average 17.1%). Chemical analyses of the oat hydrolysates indicated that the amino acid composition was nutritionally superior to that of other cereal grains. Sedova and Pleshkov (2) reported a fairly uniform pattern of amino acids in proteins of seven oat varieties. Campbell and Frey (3) used 10 interspecific crosses of *A. sativa* L. X *A. sterilis* L. to study inheritance of crude protein percentage in the groats. *A. sterilis* is a wild oat collected from the Mediterranean region for its disease resistance. It also has much higher groat-protein concentration than cultivated oats, although it has poor agronomic traits and is poorly adapted to the midwestern U.S. It appeared (3) that inheritance of protein content in *A. sativa* X *A. sterilis* crosses was fairly simple, and that heritability was high enough for researchers to succeed in breeding for high groat-protein percentage in oats by using appropriate crosses of the two species. Groat protein analyses for 15 F_2-derived oat lines of *A. sativa* X *A. sterilis* indicated that proteins of these lines were superior in lysine, leucine, and phenylalanine (and lower in threonine) than were proteins of commercially grown cultivars (4).

Wu et al. (5) milled groats of four oat cultivars and reported that the shorts and bran fractions had about twice the protein concentration of the whole oats. The 1M

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[1]Cooperative investigations between the Agricultural Research Service, North Central Region, U.S. Department of Agriculture, and Agronomy Department, College of Agriculture and Life Sciences, University of Wisconsin, Madison.

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[2]Research Chemists, Agricultural Research Service, U.S. Department of Agriculture.

[3]Present address: Director, Grain Marketing Research Center, ARS-USDA, Manhattan, Kan.

NaCl extract accounted for a large percentage of total nitrogen from all fractions; the 0.1N acetic acid extract represented a major part of the proteins from the flour fractions. When the flour fractions were air-classified, a small fraction (2 to 5% by weight) which was very rich in protein (83 to 88%) was obtained (6). Amino acid analyses of the fractions indicated high lysine levels of 3.9 to 5.0 g. per 16 g. N and adequate levels of total sulfur amino acids. In wet-milling separation, the optimum yield was obtained in dilute alkali solution (pH 9) (7). The concentrate from wet-milling contained 59 to 100% protein and had 3.9 to 4.1 g. lysine and 3.3 to 4.3 g. total sulfur amino acids per 16 g. N.

We report here the protein concentration and amino acid composition of groats and hulls of selections from 11 oat species. These species are not grown commercially in the U.S. because of their poor agronomic characteristics, but might be used as donor parents in breeding to increase the protein content and improve the amino acid composition of oat cultivars used as food or feed. The protein concentration and amino acid composition of these 11 species are compared with data from extensive surveys (from our laboratories) on composition of groats from *A. sativa* and *A. sterilis*. In addition, we determined the protein concentration and amino acid composition of hand-separated fractions of a commercial cultivar of *A. sativa* and of fractions obtained by commercial processing of oats.

MATERIALS AND METHODS

Oat Samples

The following species of *Avena* from the U.S. Department of Agriculture World Collection were included: *A. barbata, A. pilosa, A. brevis, A. strigosa, A. hirtula, A. weistii, A. abyssinica, A. magna, A. fatua, A. nuda,* and *A. murphyi*. Samples of all species (except for the hull-less *A. nuda*) were separated by hand into hulls and groats. In addition, awns were obtained from *A. magna*.

TABLE I. PROTEIN CONTENT[a] AND AMINO ACID COMPOSITION[b] OF GROATS FROM 11 OAT SPECIES

Protein or Amino Acid	Maximum	Minimum	Mean	Standard Deviation	Coefficient of Variation
Protein (%)	37.1	17.8	27.1	5.896	21.8
Lysine	4.1	3.5	3.8	0.208	5.4
Histidine	2.4	2.1	2.2	0.088	4.0
Ammonia	2.8	2.6	2.7	0.081	3.0
Arginine	7.1	6.1	6.7	0.268	4.0
Aspartic acid	8.7	7.6	8.3	0.298	3.6
Threonine	3.4	3.1	3.3	0.089	2.7
Serine	5.6	3.8	4.2	0.478	11.3
Glutamic acid	27.3	20.9	22.6	1.702	7.5
Proline	6.9	5.5	6.1	0.555	9.0
Cystine	2.5	1.9	2.3	0.195	8.6
Glycine	5.3	4.6	4.9	0.220	4.5
Alanine	4.9	4.4	4.7	0.183	3.9
Valine	5.8	5.2	5.5	0.139	2.5
Methionine	3.3	2.2	2.9	0.334	11.5
Isoleucine	4.1	3.8	3.9	0.083	2.1
Leucine	7.6	6.9	7.3	0.212	2.9
Tyrosine	3.5	2.7	3.3	0.218	6.6
Phenylalanine	5.5	5.0	5.3	0.143	2.7

[a]Dry matter basis, N X 6.25.

[b]Grams amino acid per 100 g. amino acid recovered.

TABLE II. PROTEIN CONTENT[a] AND AMINO ACID COMPOSITION[b] OF HULLS FROM 11 OAT SPECIES, AND AWNS FROM A. MAGNA

Protein or Amino Acid	Hulls					Awns
	Maximum	Minimum	Mean	Standard deviation	Coefficient of variation	
Protein (%)	8.1	2.0	4.2	2.357	56.0	3.9
Lysine	7.1	4.0	5.6	0.775	13.8	5.2
Histidine	3.2	1.0	2.1	0.678	32.2	2.7
Ammonia	6.0	2.6	4.4	1.253	28.7	6.8
Arginine	8.6	1.9	4.1	1.831	44.1	6.0
Aspartic acid	34.0	10.2	15.6	7.224	46.2	22.8
Threonine	5.8	3.5	4.8	0.688	14.3	3.8
Serine	5.8	2.7	4.6	0.850	18.5	3.7
Glutamic acid	23.4	9.3	14.5	3.814	26.4	12.4
Proline	7.4	2.4	4.8	1.587	33.0	4.6
Cystine	0.7	0.0	0.2	0.216	113.0	0.1
Glycine	7.5	3.4	5.8	1.123	19.3	4.2
Alanine	8.5	4.5	7.0	1.286	18.3	5.7
Valine	8.0	4.3	6.4	1.194	18.6	5.4
Methionine	3.2	1.7	2.3	0.469	20.2	1.8
Isoleucine	4.6	2.5	3.9	0.755	19.4	3.3
Leucine	8.6	4.3	7.2	1.375	19.0	5.9
Tyrosine	4.7	1.3	2.3	1.167	49.8	2.0
Phenylalanine	5.2	3.1	4.3	0.649	15.2	3.7

[a]Dry matter basis, N X 6.25.

[b]Grams amino acid per 100 g. amino acid recovered.

TABLE III. AVERAGE PROTEIN CONTENT[a] AND AMINO ACID COMPOSITION[b] OF GROATS IN 289 CULTIVARS OF A. SATIVA 68 SELECTIONS OF A. STERILIS, AND 11 OTHER OAT SPECIES

Protein or Amino Acid	A. sativa	A. sterilis		11 Other Oat Species
		Range	Average	
Protein (%)	17.1	22.1–31.4	25.9	27.1
Lysine	4.2	3.7– 4.4	4.0	3.8
Histidine	2.2	2.2– 2.5	2.4	2.2
Ammonia	2.7	2.8– 3.3	2.9	2.7
Arginine	6.9	6.7– 7.4	7.0	6.7
Aspartic acid	8.9	8.0– 9.8	8.7	8.3
Threonine	3.3	3.2– 3.7	3.3	3.3
Serine	4.2	4.1– 4.6	4.3	4.2
Glutamic acid	23.9	20.8–23.7	22.6	22.6
Proline	4.7	4.5– 6.3	5.8	6.1
Cystine	1.6	1.0– 2.1	1.8	2.3
Glycine	4.9	4.7– 5.1	4.8	4.9
Alanine	5.0	4.3– 4.8	4.4	4.7
Valine	5.3	5.5– 5.8	5.6	5.5
Methionine	2.5	1.6– 2.8	2.4	2.9
Isoleucine	3.9	3.9– 4.2	4.0	3.9
Leucine	7.4	7.3– 7.6	7.5	7.3
Tyrosine	3.1	2.9– 3.4	3.2	3.3
Phenylalanine	5.3	5.2– 5.6	5.4	5.3

[a]Dry matter, N X 6.25.

[b]Grams amino acid per 100 g. amino acid recovered.

The protein concentration and amino acid composition were compared with the results of a survey of 289 cultivars of *A. sativa* (1) and of analyses of 68 selections of *A. sterilis* (unpublished).

Groats of *A. sativa*, cv. Orbit, were hand-dissected into embryonic axis, scutellum, bran (including the aleurone layer), and starchy endosperm as described elsewhere (8). Commercial oat products (from a blend of oats from the North Central U.S.) were obtained from Quaker Oats Co., Barrington, Ill.

Analytical Methods

Moisture and protein were determined according to the American Society of Brewing Chemists methods of analysis (9). Percent protein is reported as Kjeldahl N X 6.25, on a moisture-free basis. Amino acid analyses were performed on a Beckman 121 automatic amino acid analyzer as described previously (10). Average recoveries of amino acids were 92.0% for the groats and 60.3% for the hulls, indicating relatively high concentration of nonprotein N compounds in the latter.

RESULTS AND DISCUSSION

Statistical evaluation of data on protein concentration and amino acid composition of groats and hulls of the 11 oat species is summarized in Tables I and II, respectively. The results in Tables I and II reflect combined effects of analytical and genetic variability. Average analytical coefficient of variation in amino acid assays of oat groats in our laboratories is 5.5%; the coefficient is somewhat larger in sulfur-containing amino acids and is consistently smaller in other amino acids,

TABLE IV. PROTEIN CONTENT[a] AND AMINO ACID COMPOSITION[b] OF HAND-SEPARATED FRACTION OF GROATS

Protein or Amino Acid	Whole Groats	Embryonic Axis	Scutellum	Bran[c]	Endosperm
Protein (%)	13.8	44.3	32.4	18.8	9.6
Lysine	4.5	8.2	6.9	4.1	3.7
Histidine	2.4	3.9	3.6	2.2	2.2
Ammonia	2.7	1.9	1.8	2.5	2.9
Arginine	6.8	8.3	9.0	6.8	6.6
Aspartic acid	8.7	10.2	9.7	8.6	8.5
Threonine	3.4	5.0	4.7	3.4	3.3
Serine	4.6	4.8	5.0	4.8	4.6
Glutamic acid	21.7	14.2	14.9	21.1	23.6
Proline	5.5	3.3	3.6	6.2	4.6
Cystine	2.1	0.5	1.0	2.4	2.2
Glycine	5.2	6.3	6.2	5.4	4.7
Alanine	5.0	7.2	6.9	5.1	4.5
Valine	5.5	6.0	6.2	5.5	5.5
Methionine	2.2	2.2	2.1	2.1	2.4
Isoleucine	3.9	3.9	3.8	3.8	4.2
Leucine	7.6	7.1	7.1	7.4	7.8
Tyrosine	3.0	2.9	3.0	3.5	3.3
Phenylalanine	5.2	4.2	4.4	5.1	5.6

[a]Dry matter, N X 6.25.

[b]Grams amino acid per 100 g. amino acid recovered.

[c]Includes aleurone layer.

TABLE V. PROTEIN CONTENT[a] AND AMINO ACID COMPOSITION[b] OF COMMERCIALLY MILLED OATS

Protein or Amino Acid	Heavy Oats	Light Oats	Groats	Hulls	Flakes
Protein (%)	13.4	9.6	18.9	5.7	17.6
Lysine	4.2	5.2	3.9	4.9	4.1
Histidine	2.4	2.7	2.3	2.4	2.4
Ammonia	3.3	3.8	3.2	3.6	3.2
Arginine	6.4	6.3	6.2	6.8	6.0
Aspartic acid	9.2	11.1	9.0	10.5	9.0
Threonine	3.3	4.1	3.1	4.1	3.1
Serine	4.0	4.5	3.9	4.6	4.0
Glutamic acid	21.6	20.0	22.4	20.3	22.7
Proline	5.7	3.1	6.2	2.4	6.1
Cystine	1.7	0.4	2.0	0.5	1.7
Glycine	5.1	6.0	5.0	6.1	5.0
Alanine	5.1	5.5	5.0	5.4	5.0
Valine	5.8	6.2	5.7	6.4	5.8
Methionine	2.3	1.5	2.5	1.5	2.4
Isoleucine	4.2	4.5	4.3	4.5	4.3
Leucine	7.5	7.6	7.4	7.8	7.5
Tyrosine	2.6	2.4	2.5	2.9	2.1
Phenylalanine	5.4	5.3	5.5	5.3	5.6

[a]Dry matter, N X 6.25.

[b]Grams amino acid per 100 g. amino acid recovered.

especially glutamic acid (1.5%). The coefficient of variation in analyses of protein-poor hulls would be expected to be somewhat larger than in protein-rich groats.

It was emphasized previously (1) that genetic variability within a population is a prerequisite for progress through selection for a specific parameter. A comparison of results in Table I with previously reported results for *A. sativa* (1) is given in Table III. There was more variability in protein concentration of groats in the 11 oat species than in 289 cultivars of *A. sativa*. However, there were no significant differences in samples from the two studies in levels and variability in amino acids (including those that might be limiting in oat groats, i.e. lysine, threonine, and sulfur-containing amino acids).

The groats contained on the average about seven times as much protein as hulls. The groat proteins were richer than the hulls in glutamic acid, arginine, proline, cystine, tyrosine, and phenylalanine, and lower in lysine, aspartic acid, threonine, glycine, alanine, and valine (Tables I and II). Awns were similar to hulls in protein content and amino acid composition.

Although groats from *A. sterilis* were on the average richer in total protein than groats from *A. sativa*, there were no consistent differences in amino acid composition, including the potentially limiting ones.

These results are, admittedly, disappointing. However, two points should be emphasized: a) oat groats, on the average, are highest in protein among cereal grains; and b) the oat groat proteins have an excellent amino acid balance (as determined by chemical analyses). Inasmuch as we do not seem to have readily available genetic stocks to improve the amino acid balance of oats, it might be advisable, at this stage at least, to concentrate efforts on increasing protein content by genetic selection and by cultural practices, provided amino acid composition and balance are not affected adversely. Another possibility would be to select for oat cultivars with unique grain morphology, i.e., large germ or multiple-aleurone layers that are rich in protein and lysine.

Results of analyzing hand-dissected oat fractions are summarized in Table IV. The protein-rich germ tissues were richer (than the whole groat) in several amino acids, especially lysine, histidine, arginine, aspartic acid, and threonine. Germ proteins are relatively poor sources of amino acids of storage proteins (glutamic acid and proline) and of cystine. The bran (including the aleurone layer) contained almost twice as much total protein and had a slightly better amino acid balance (more lysine and less glutamic acid) than the starchy endosperm.

Lightweight oats, which are high in hulls, contained less protein than large (heavy) oats (Table V). The relatively higher concentration in the hulls than in the groats of lysine, aspartic acid, and threonine, and lower concentrations of glutamic acid, proline, and sulfur-containing amino acids were reflected in the differences in amino acid composition between heavy and lightweight oats. In protein contents and amino acid composition the flakes resembled the groats from which the flakes were produced.

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